California in 2050: Some Sizzling Predictions

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California is Experiencing Climate Change Now, and Larger Changes are on the Horizon

- As part of the CPUC's Policy & Planning Division's (PPD) ongoing work on climate change, PPD produced this slide deck to provide a review of recent research on the potential impacts of climate change to California in the near future.

- Understanding this research will assist the Commission and its stakeholders in their efforts to adapt the electric sector to those changes and consider adaptation issues in commission proceedings, especially those considering long-term investments.

Key Findings from Recent Research on Future Climate Impacts to California

- Extreme heat days in cities like Fresno will likely triple by 2030, with a 60% chance of at least 3 heat waves lasting more than 6 days each year. By 2050 it will be a 90% chance. (***Cal-adapt***)

- There is a 67% chance that sea levels in California will reach 6 inches by 2030 and one foot by 2050. Under current emissions scenarios, by 2100 sea levels could be up to 3.5 feet and potentially up to 10 feet. (***Ocean Protection Council Working Group***)

- There is an 80% chance of having a 30-year drought in the Southwest under current emission trajectories. (***NASA***)

- Wildfires are expected to burn 77% more area by 2050. (***UCLA****)*

Presentation Outline

- Review a striking federal government study documenting significant global changes and specifically attributing those changes to human activity

- Review alarming research findings predicting dramatic changes in California for increasing:

    1. Temperatures
    2. Sea Level Rise
    3. Drought and Deluge
    4. Wildfires

US Global Change Research Program

- USGCRP was mandated by Congress in 1990 to "assist the Nation and the world to understand, assess, predict, and respond to human-induced and natural processes of global change." There are 13 participating US agencies including: NASA, DOE, and EPA

- Striking highlights from the recently released ***Climate Science Special Report***:
  - Average global temperatures are rising faster than they have at any time in the past 1,700 years; they have increased by 1.8°F (1°C) from 1901-2016; 1.2°F (.65°C) of that change occurred between the period of 1986-2016
  - Human activities are the primary drivers of recent temperature rise; they are responsible for 92-123% of the observed changes from 1951 to 2010
  - 2014, 2015, and 2016 all set global temperature records
  - There is "high confidence" that recent record-setting temperatures will become "common" in the next few decades

Key Findings From USGCRP Report (Cont.)

- California is already experiencing dramatic impacts from climate change with as little as 1.8°F (1°C) global average temperature increase.

- Even if emissions halted today, the globe is committed to at least an additional 1.1°F (.6°C) warming, reaching 2.9°F (1.6°C) – pushing us very close to the point many scientists believe is the "point of no return" – 3.6°F (2°C).

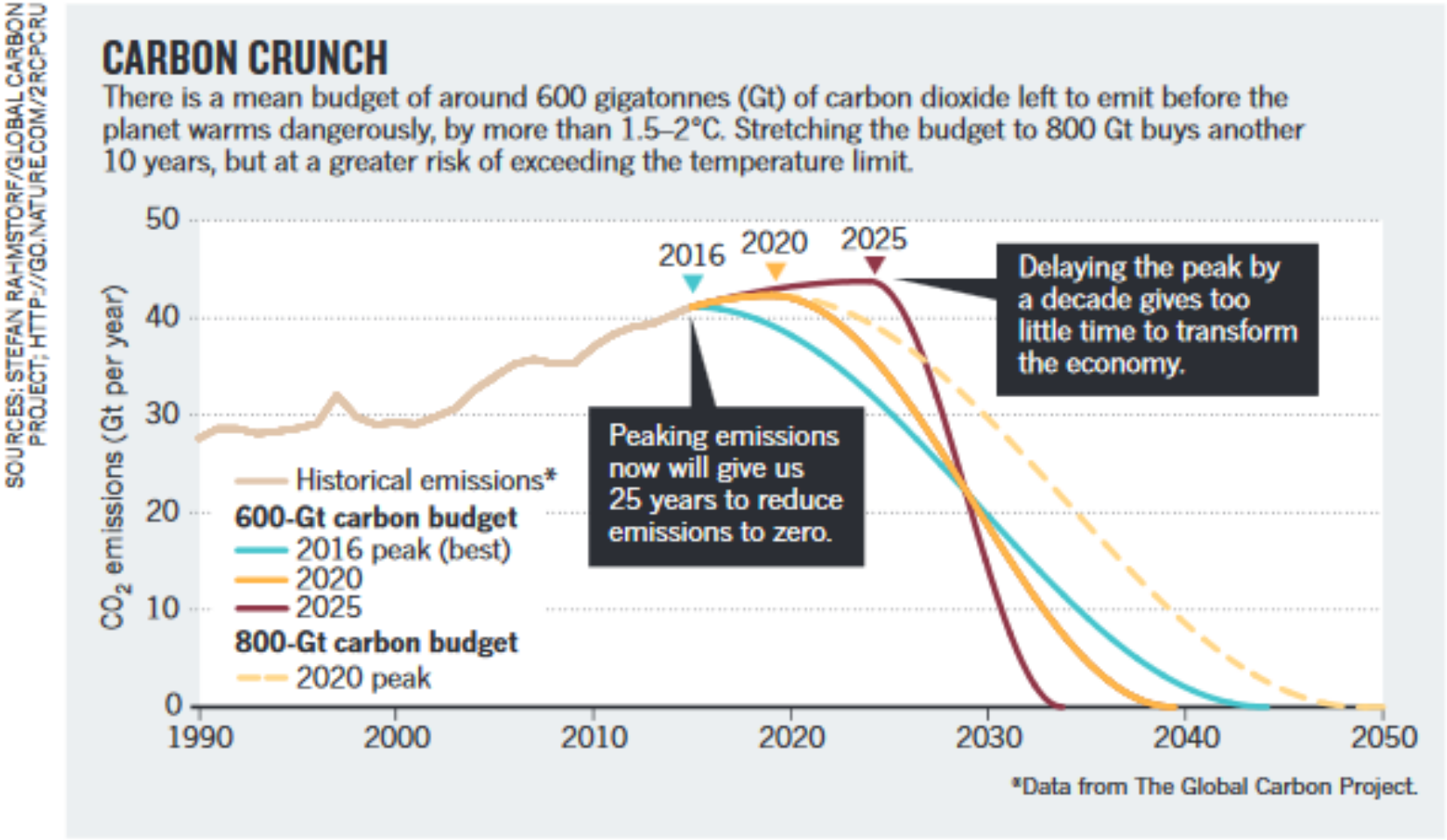
- If emissions continue unabated we could reach 9°F (5°C) by end of century. Humans have never lived on a planet that hot.

Climate Science Special Report Projects Alarming Temperature Increases

- Between 2021-2050 – temperatures are projected to rise by 4.3°F (2.38°C)
  - The increase in this time period is projected to be 2.5°F (1.38°C), which is in addition to the increase of 1.8°F (1°C) already experienced
  - Scientists generally believe 3.6°F (2 °C) is a critical turning point

- Between 2071-2100 – temperature increases are projected to range from 4.6°F (2.38°C) to 13.7°F (7.6°C) depending on emissions
  - The lower emissions scenario (RCP 4.5) would see additional increases of 2.8°-7.3°F (1.5-4°C) above the increases already experienced
  - The higher emission scenario (RCP 8.5) would see additional increases of 5.8°-11.9°F (3.2-6.6°C)
  - We are currently on the higher emissions path

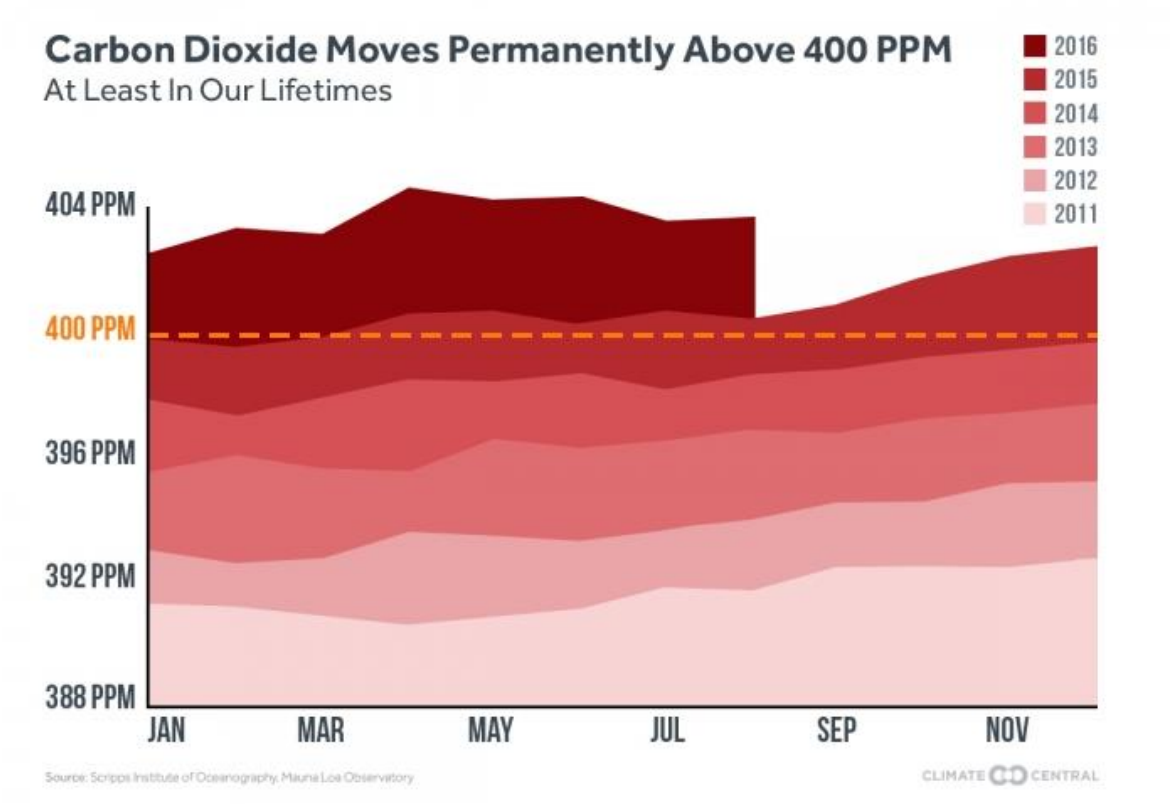
In Order to Avoid the Worst Impacts, Emissions Must Be Reduced Significantly Now



-- Governor Brown signed onto an article that presented this chart

-- Even California's aggressive policies do not target zero emissions by 2040 or 2050

Global Temperatures are Increasing Due to Higher Concentrations of CO2 in the Atmosphere



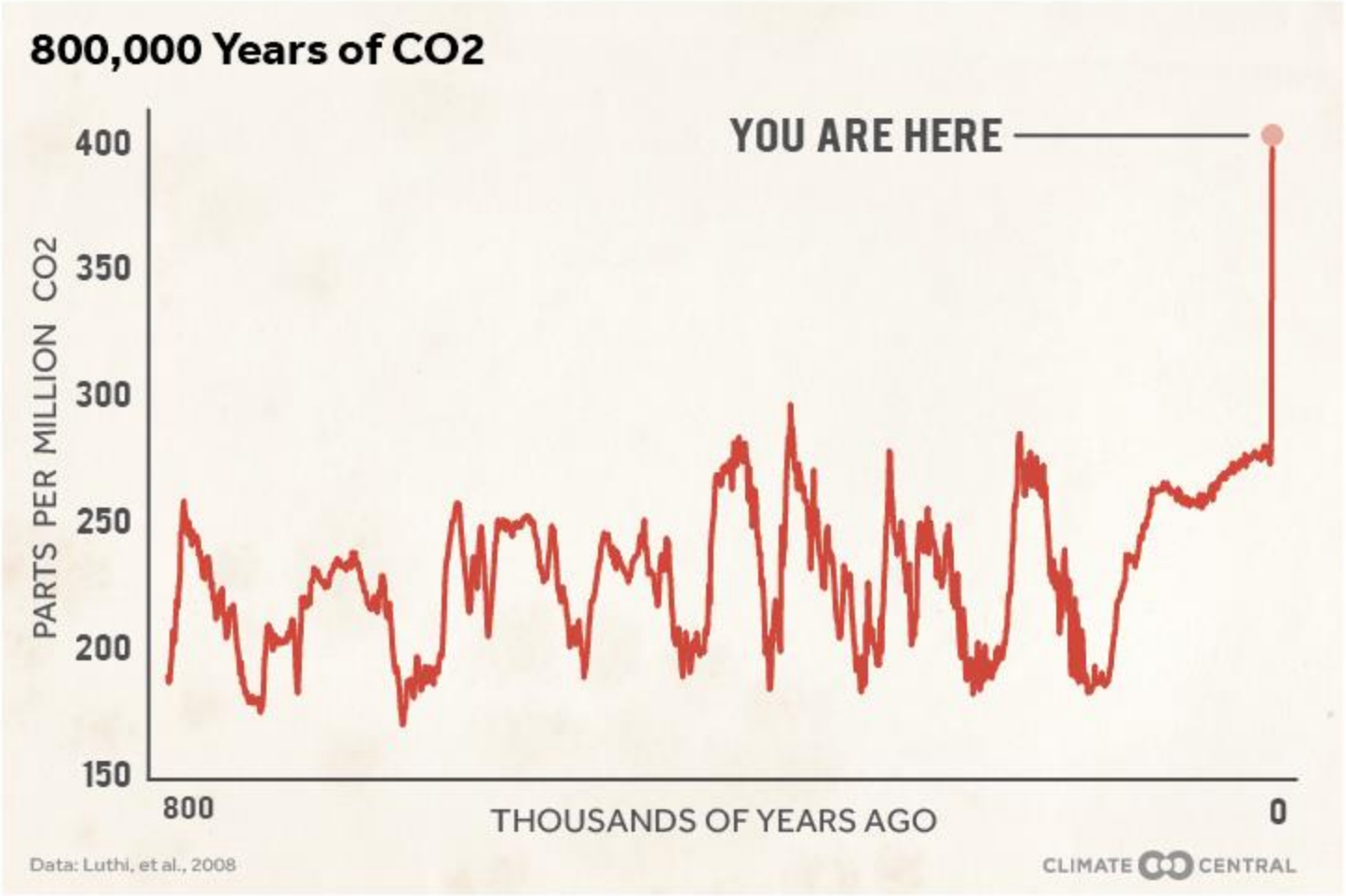
-- CO2 concentrations in the atmosphere drive temperature increases

-- CO2 is increasing at the rate of 3.2 ppm per year; by 2047 we will reach 500 PPM

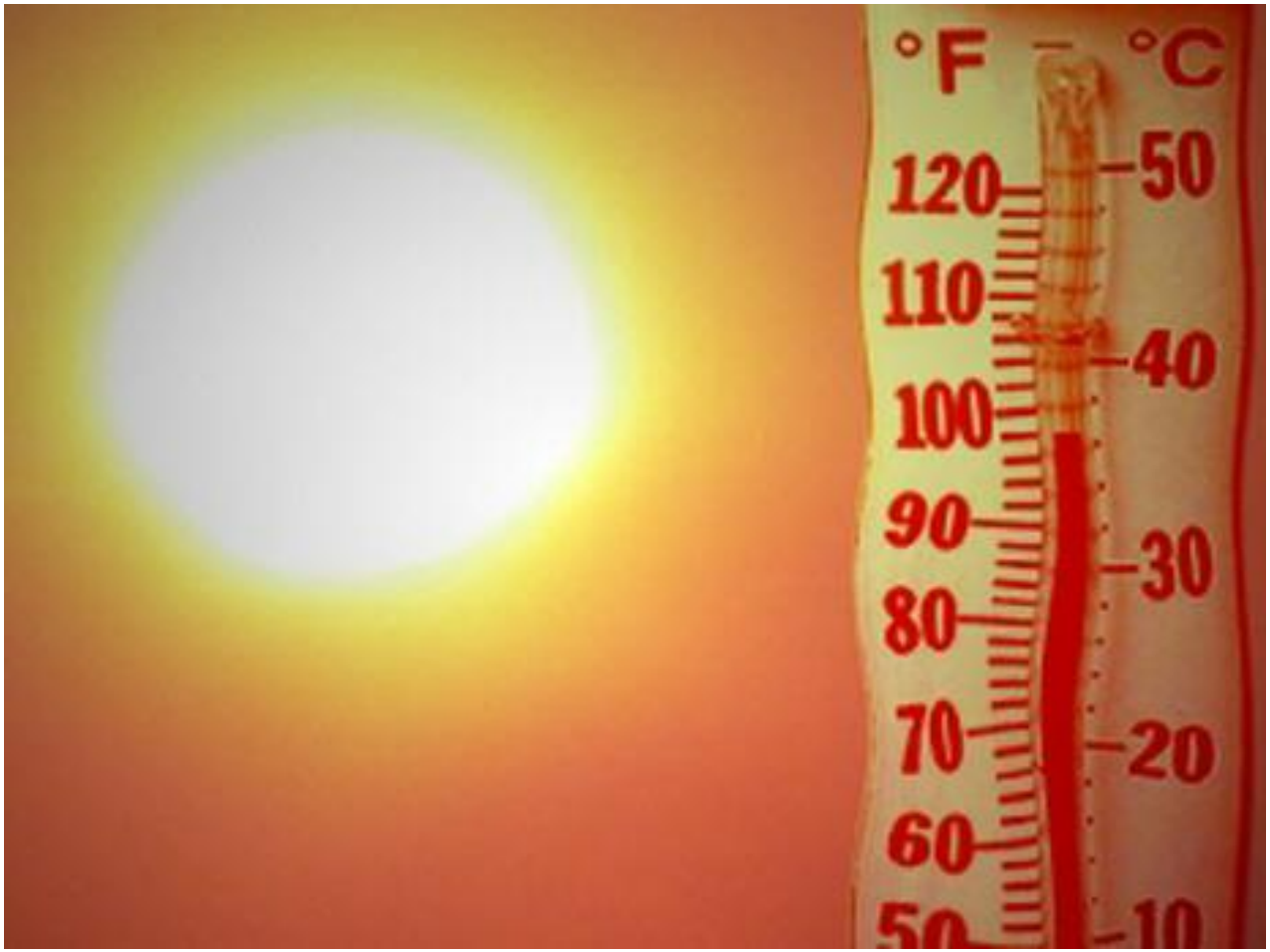
-- 400PPM could commit the globe to average warming of between 1.8° – 7.2°F (1°-4°C)

– 500PPM could commit the globe to warming of 3.6°- 9°F (2°-5°C) (***Climate Central***)

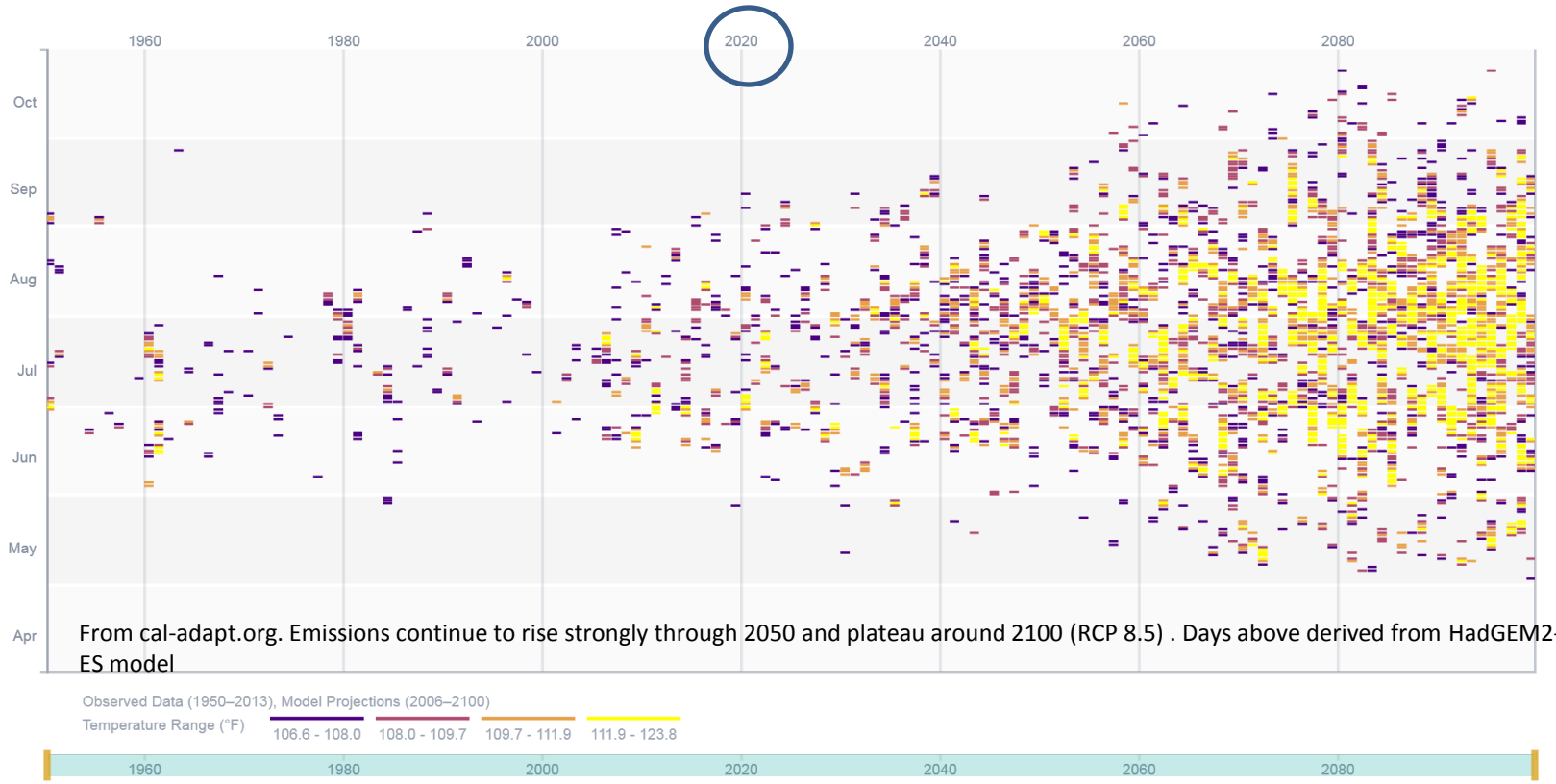
FYI: The Last Time CO2 Levels Were This High, Humans Didn't Exist



1. Temperatures In California Are Rising



Fresno Could Experience Extreme Heat



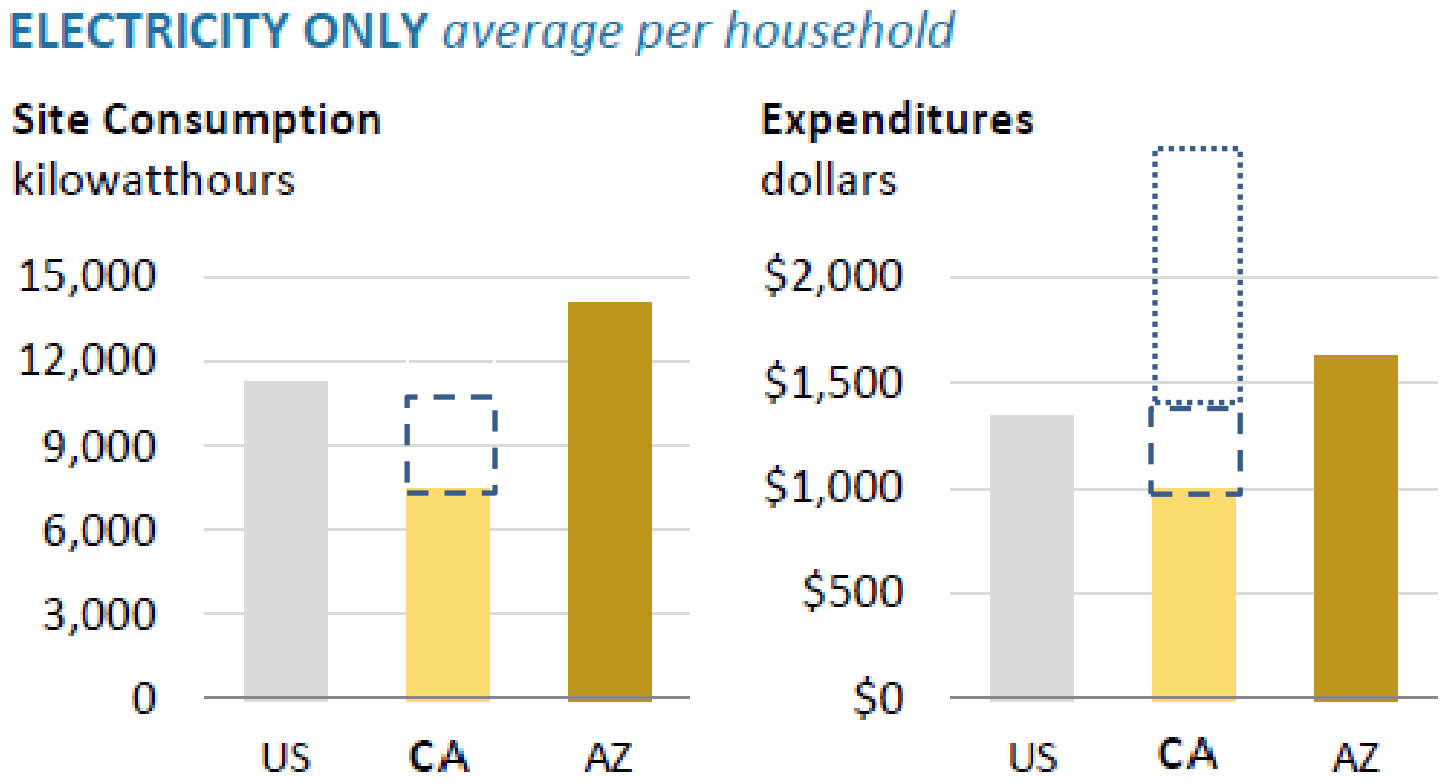
From cal-adapt.org. Emissions continue to rise strongly through 2050 and plateau around 2100 (RCP 8.5) . Days above derived from HadGEM2-ES model

-- Graph from Cal-adapt.org; using HadGEM2-ES model (dry and hot scenario)
-- Each dot represents a day over 106.6°F; the yellow dots are days up to 124°F
-- Starting in 2020 the number and intensity of extreme heat days clearly increase

Extreme Heat in Fresno: Significant Increase in the Number of Days over 106.6 °F

- Historical Average
  - Historical Average is 4 per year
  - More recent average is 6
  - Historical average of heat waves (>5 days): 2.5
- Between 2030-2040
  - No. of extreme heat days and nights: 7-32, average 20
  - No. of heatwaves: annual average is 2.5 lasting 6 days (plus a 60% chance of having at least three)
- Between 2040-2050
  - No. of extreme heat days and nights: 9-37, average 22
  - No. of heatwaves: annual average is 2.5 lasting 9 days (plus a 90% chance of having at least 3, and a 50% of having at least 1 lasting >11 days)

California Becomes Arizona?



-- 96% of residential customers in AZ have air conditioning, only 60% in CA currently do

-- Studies predict increasing temperatures will cause more Californians to buy air conditioning units. Even a 50% increase in residential usage brings California close to Arizona household usage, and even closer in prices. The <u>average</u> cost is $1500 per household, which means the higher end could be $3000 per household. (***EIA***)

Impacts of Extreme Heat to the Grid

- Many studies show that extreme heat has significant impact to the grid including:
  - Line sag decreases transmission efficiency
  - Thermal efficiency of power plants decrease
  - Thermal efficiency of solar panels also decrease and wind speeds often slow (a new study shows decrease in wind production across the northern hemisphere of 8-40%)
  - Assets such as transformers can not cool down and overheat, causing them to break or to operate less efficiently and require more maintenance
  - Cooling demand increases significantly during both day and night

2. Sea Level is Rising in California

Studies Show Sea Levels Are Rising

(b) San Francisco, Golden Gate

Feet above 1991-2009 mean	MEDIAN	LIKELY RANGE	1-IN-20 CHANCE	1-IN-200 CHANCE
Year / Percentile	*50% probability SLR meets or exceeds...*	*67% probability SLR is between...*	*5% probability SLR meets or exceeds...*	*0.5% probability SLR meets or exceeds...*
2030	0.4	0.3 – 0.5	0.6	0.8
2050	0.9	0.6 – 1.1	1.4	1.9
2100 (RCP 2.6)	1.6	1.0 – 2.4	3.2	5.7
2100 (RCP 4.5)	1.9	1.2 – 2.7	3.5	5.9
2100 (RCP 8.5)	2.5	1.6 – 3.4	4.4	6.9
2100 (H++)	10			
2150 (RCP 2.6)	2.4	1.3 – 3.8	5.5	11.0
2150 (RCP 4.5)	3.0	1.7 – 4.6	6.4	11.7
2150 (RCP 8.5)	4.1	2.8 – 5.8	7.7	13.0
2150 (H++)	22			

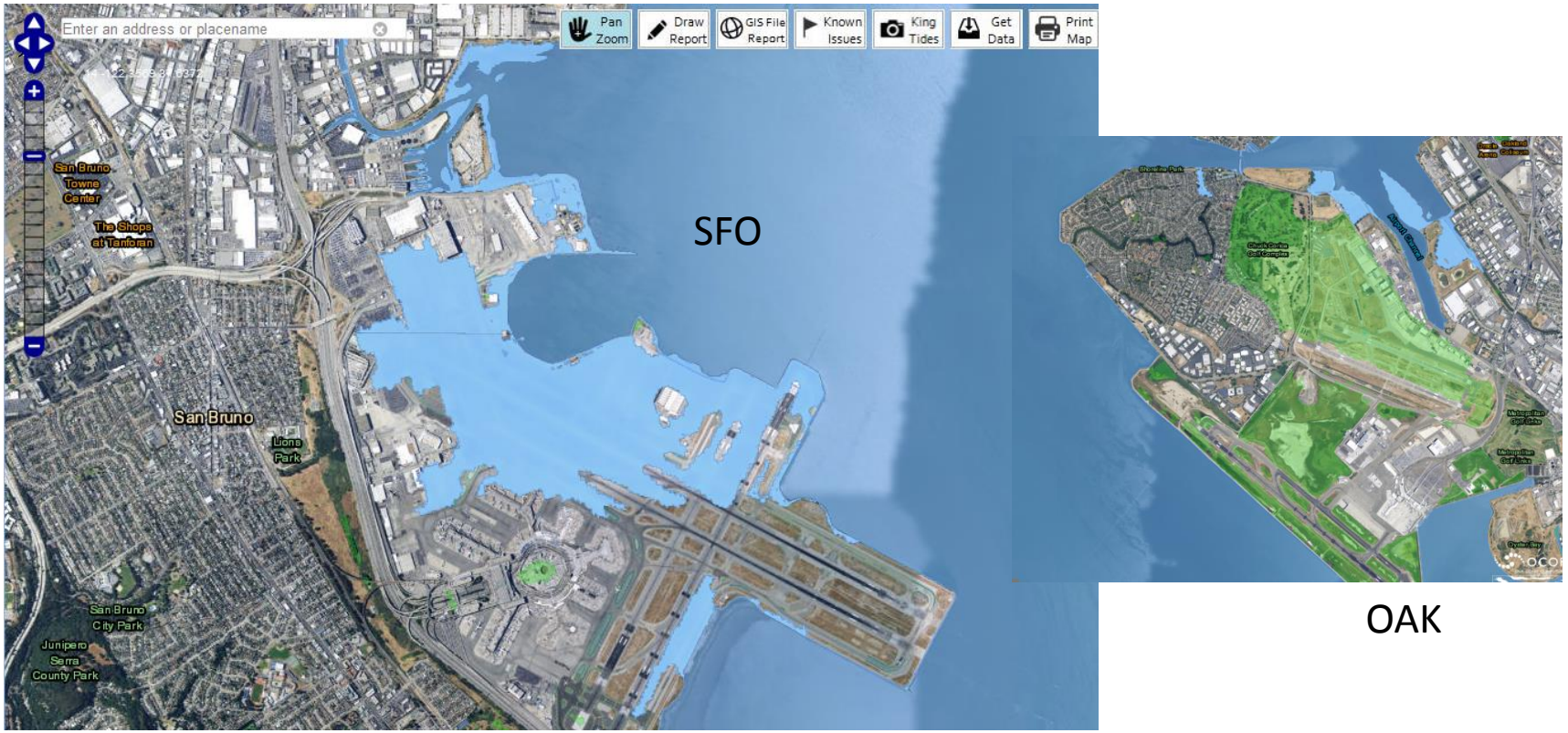
SEA-LEVEL RISE PROJECTIONS | 26

-- This chart is from a report issued in 2017 called ***Rising Seas In California***

-- There is a 67% probability that seas will rise in San Francisco by 6 inches to 1 foot by 2050; models show similar rise in most of California

-- Sea Level rise in California is more affected by the Antarctic sea melt

Sea Rise Will Quickly Impact Critical Infrastructure



-- SFO and OAK under 25 cm (9.8 inches) sea level rise with 20-year storm surge
-- Graphic From Our Coast, Our Future (OCOF) collaborative

Critical Electric Sector Infrastructure Could Also be Impacted: IOUs Assessing Asset-by-Asset Climate Vulnerabilities

Table 3: Percent exposure of electric assets to 100- and 500-year FEMA flood zones

Electric Assets	FEMA 100-Flood Zone Exposure	500-Year Flood Zone Exposure
Distribution Lines	9%	13%
Distribution Transformers (Pad-Mount)	6%	17%
Transmission Lines	14%	18%
Substations	26%	39%
Power Generation Facilities	0%	0%

-- This chart is from a report issued in 2016 by Pacific Gas & Electric, Climate Change Vulnerability Assessment

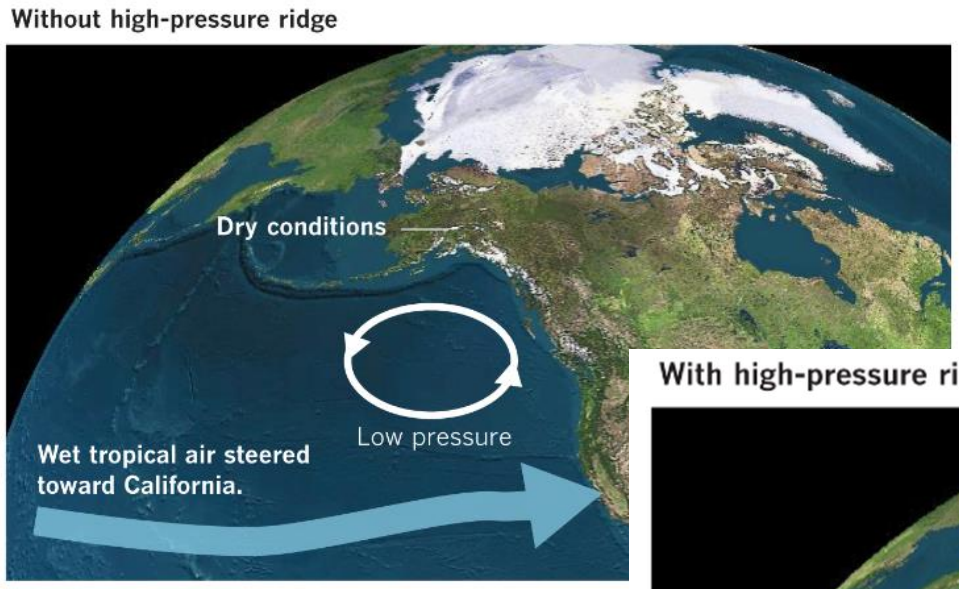
Figure 6: PG&E's electric substations identified within the 100-year FEMA flood zone

Impacts of Sea Level Rise to the Grid

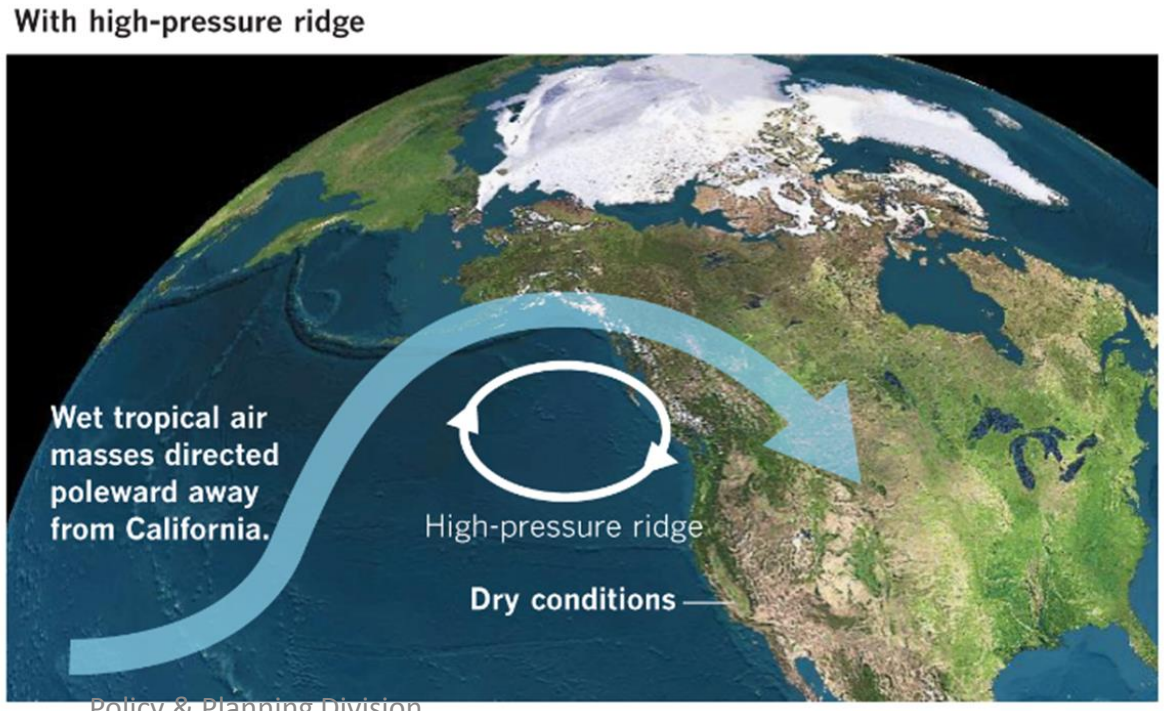
- Studies have shown that sea level could have significant impact to the electric and natural gas infrastructure
- Sea water is corrosive and could permanently damage equipment
- The weight of sea waters rising could impact natural gas pipelines
- All three IOUs anticipate that major substations will be impacted with 24 inches of sea level rise

3.1 Drought in California

Melting Arctic Sea Ice May Cause Multi-year Droughts in California



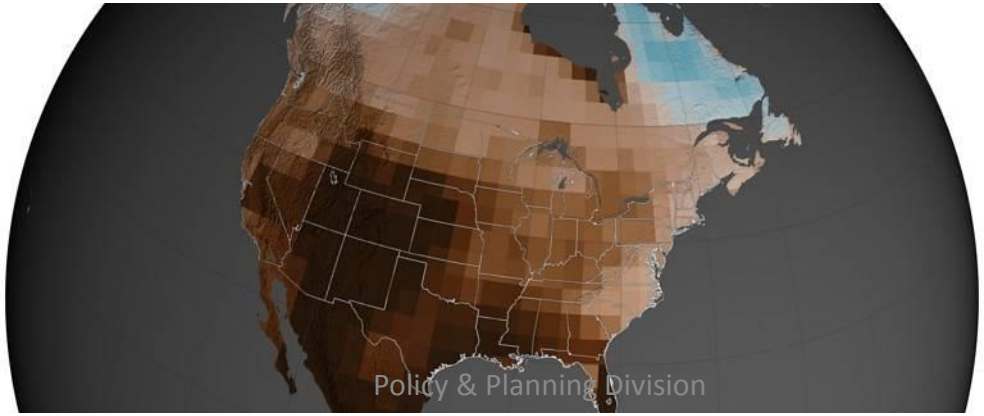
-- Current levels of sea ice steer wet tropical air towards California



-- Less Arctic ice drives wet air away from California and encourages the formation of high pressure ridges, which prevents precipitation from reaching California

30-yr Mega Droughts Predicted for Future

- NASA study predicts that droughts in the Southwest could be drier and longer than they have been in the last 1,000 years.
- Results of modeling show drought similar to 1930s 8-year long dustbowl could last 30-35 years.
- Likelihood of a mega drought lasting more than 3 decades is:
  - 12% if emissions stop today
  - 60% if emissions decline starting mid century
  - 80% if emissions continue to increase along current trajectories throughout the 21st century



Impacts of Drought to the Grid

- Scientists have highlighted a variety of concerns regarding the impact of drought on the California Grid:
  - Carbon emissions could increase if hydropower decreases, as California relies on hydropower for zero-carbon emissions
  - Lack of water would impact operations of many types of power plants, including natural gas and solar thermal, which use water for operations
  - Drawing groundwater causes subsidence and impacts all infrastructure including electric sector infrastructure
  - Droughts are increasingly regional, so Northwest hydropower production will decrease at the same time that increasing temperatures increase demand in the WECC.

3.2 Droughts Interspersed With Deluge

Atmospheric Rivers Are Predicted to Become More Intense

- California receives the majority of its rainfall/snowfall from storms caused by atmospheric rivers (aka Pineapple Express)

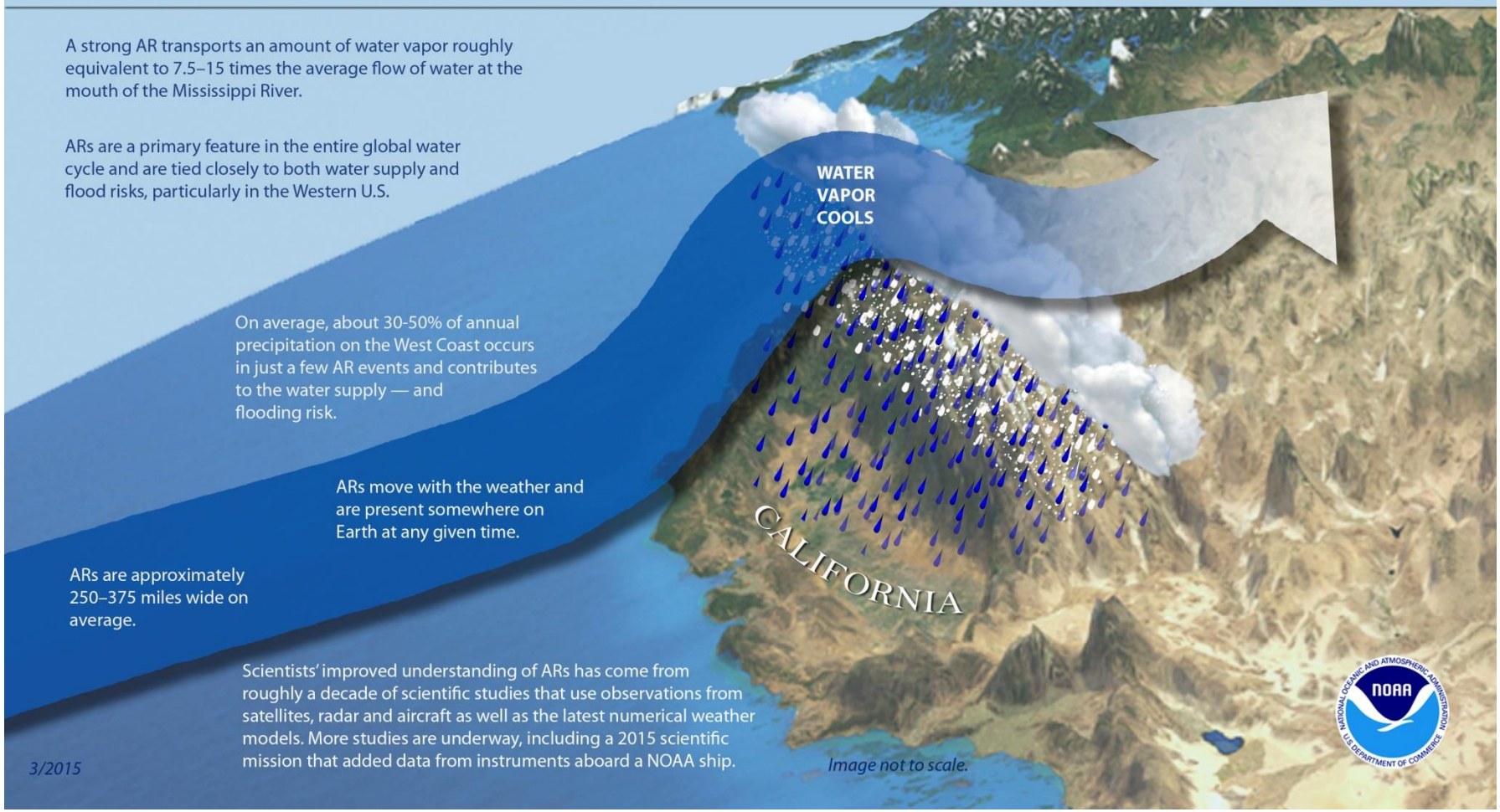
- Climate models and basic physics suggest that atmospheric rivers will become moister and more intense in the future, as a warmer atmosphere can hold more water vapor (about 4% more for every degree 1°F of warming). (***MIT***)

- A recent study by the Massachusetts Institute of Technology estimates the number of storms will more than double (from 4 to 9) by 2100.

- Experts say more modeling of atmospheric rivers must be conducted to fully understand changes due to climate change.

The science behind atmospheric rivers

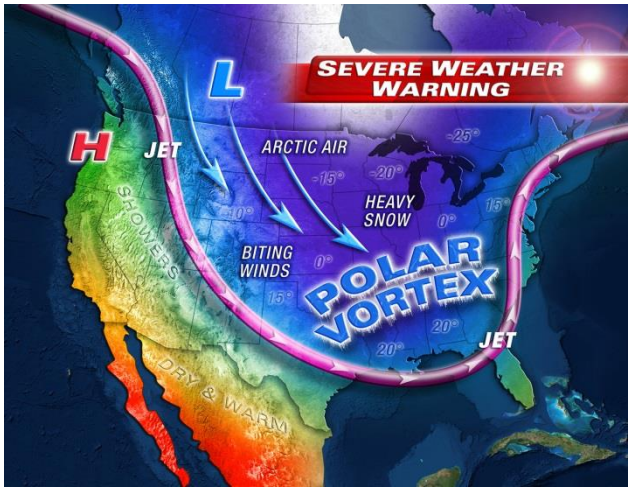
An atmospheric river (AR) is a flowing column of condensed water vapor in the atmosphere responsible for producing significant levels of rain and snow, especially in the Western United States. When ARs move inland and sweep over the mountains, the water vapor rises and cools to create heavy precipitation. Though many ARs are weak systems that simply provide beneficial rain or snow, some of the larger, more powerful ARs can create extreme rainfall and floods capable of disrupting travel, inducing mudslides and causing catastrophic damage to life and property. Visit www.research.noaa.gov to learn more.



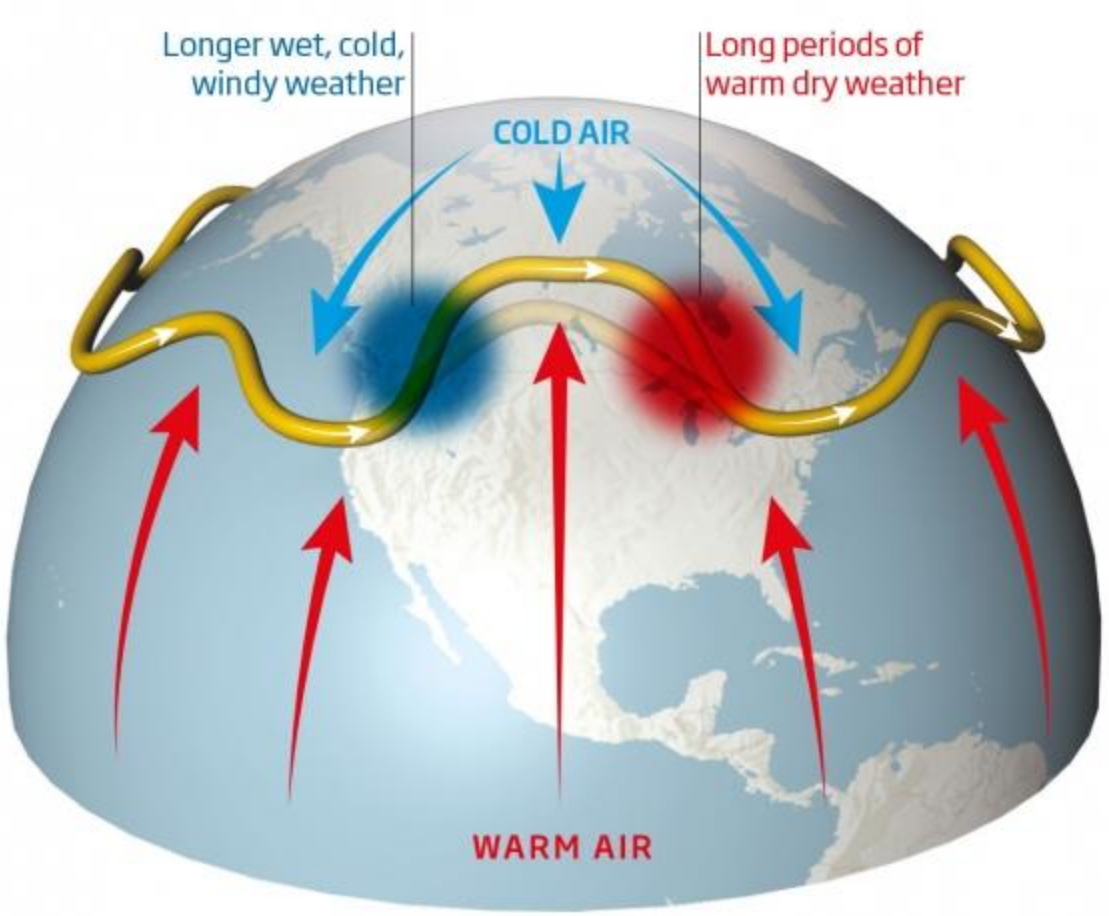
January 2016 News Headline: Warming Pacific Ocean Could Bring Hurricanes

-- Only two storms have hit Southern California; one direct and one that hit Baja first
-- As seas warm, storms could hold together longer and hit Southern California more often, coming over from Hawaii or up from Mexico

Melting Arctic Ice Also Causes the Polar Vortex



-- As the cool air of the Arctic becomes warmer, the jet stream slows down, becomes wavy, and releases the cold air further south



Impacts of Deluge to the Grid

- Scientists have highlighted concerns of impact of atmospheric rivers to the electric sector including:
  - Our current reservoir system is not designed to handle significant amounts of rain in a single year
  - There are heightened risk of massive mud slides in areas scarred by wildfires, which can wipe out electric sector infrastructure

- A new climate regime swinging between extreme drought and extreme rainfall will require new approaches in planning.

- MIT is conducting research to understand the impacts of deluge to the grid

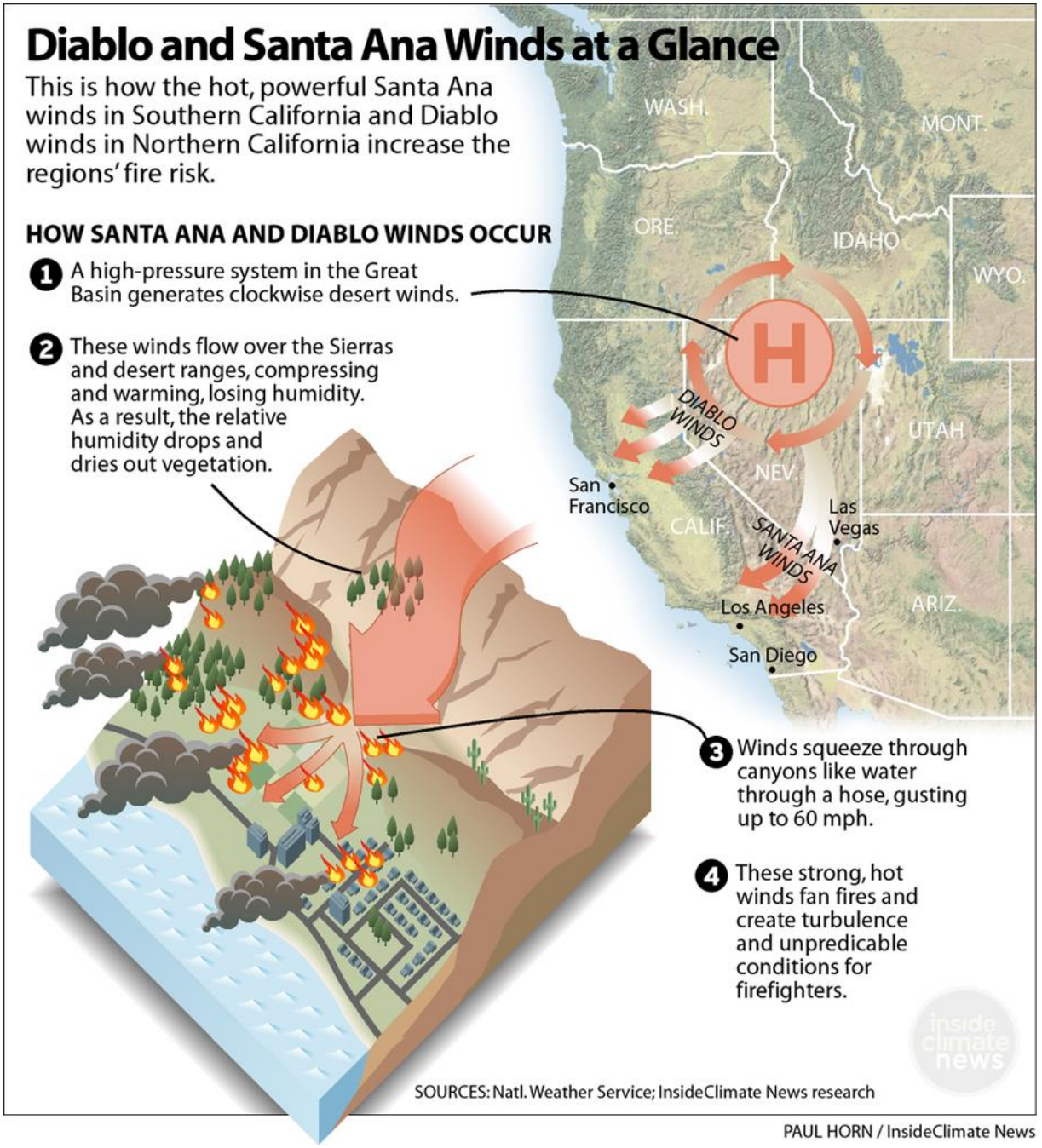
4. Wildfires in California

The 2017 Thomas fire as seen from space

Wildfires or Firestorms?

- Wildfires are exacerbated by drought, atmospheric rivers, temperature increases, and by high pressure systems inland which increase wind (Santa Anas)

- US Forest Service says an “unprecedented” 165 million trees are dead in California, and are fodder for wildfire and bark beatles


Diablo and Santa Ana Winds at a Glance
This is how the hot, powerful Santa Ana winds in Southern California and Diablo winds in Northern California increase the regions' fire risk.
HOW SANTA ANA AND DIABLO WINDS OCCUR
1 A high-pressure system in the Great Basin generates clockwise desert winds.
2 These winds flow over the Sierras and desert ranges, compressing and warming, losing humidity. As a result, the relative humidity drops and dries out vegetation.
3 Winds squeeze through canyons like water through a hose, gusting up to 60 mph.
4 These strong, hot winds fan fires and create turbulence and unpredicable conditions for firefighters.
WASH.
MONT.
ORE.
IDAHO
WYO.
H
DIABLO WINDS
UTAH
NEV.
San Francisco
CALIF.
Las Vegas
SANTA ANA WINDS
Los Angeles
ARIZ.
San Diego
SOURCES: Natl. Weather Service; InsideClimate News research
PAUL HORN / InsideClimate News

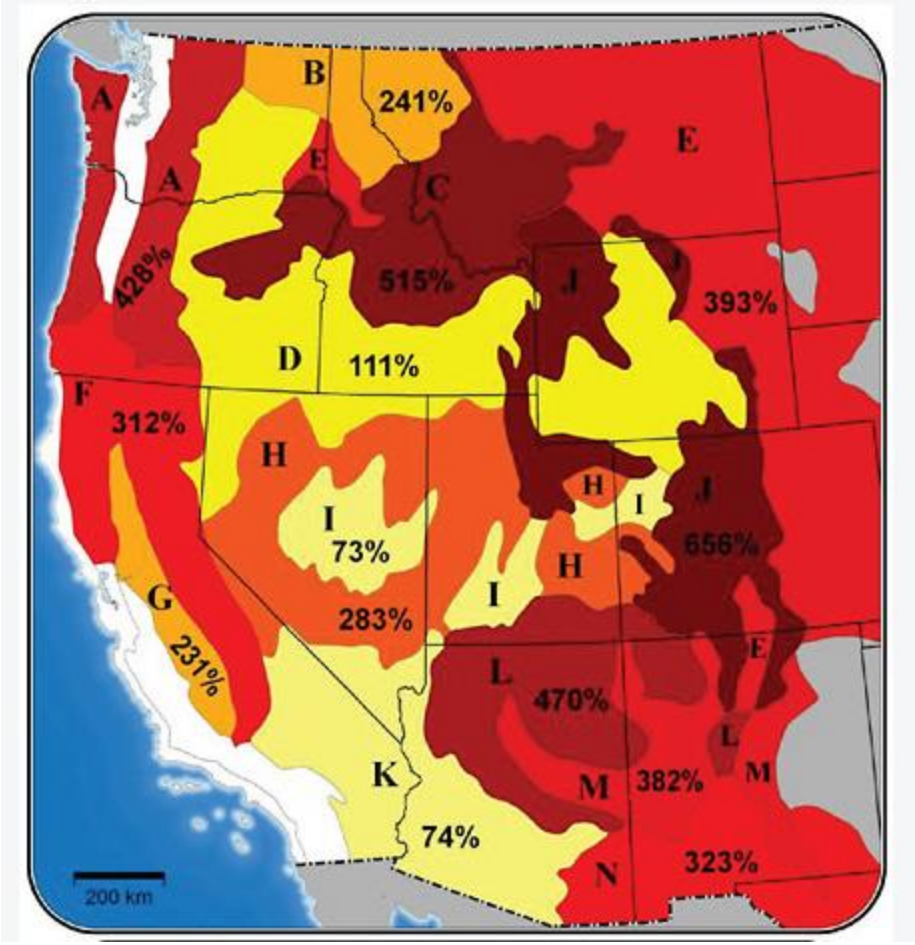
Future Wildfires

- As the temperatures in the Great Basin increase, the length of the Santa Ana season is likely to extend beyond the current October to December timeframe.

- Under a scenario where the melting artic creates stronger and more frequent high pressure systems over California, the land is drier and more prone to wildfire throughout that season.

- However, recent research shows the frequency of high-wind events has actually decreased over the last several decades, which shows that more research is needed. (***UCLA***)

Future Wildfires To Significantly Increase in Size



Percent Increase in Median Annual Area Burned with a 1ºC Increase in Global Average Temperature (National Research Council)

- Research by UCLA projects that fires in Southern California will become more destructive because of hotter drier conditions.
- The area burned in Santa Ana fires is projected to increase 64%
- The area burned in NON-Santa Ana fires is projected to increase by 77% by 2050.

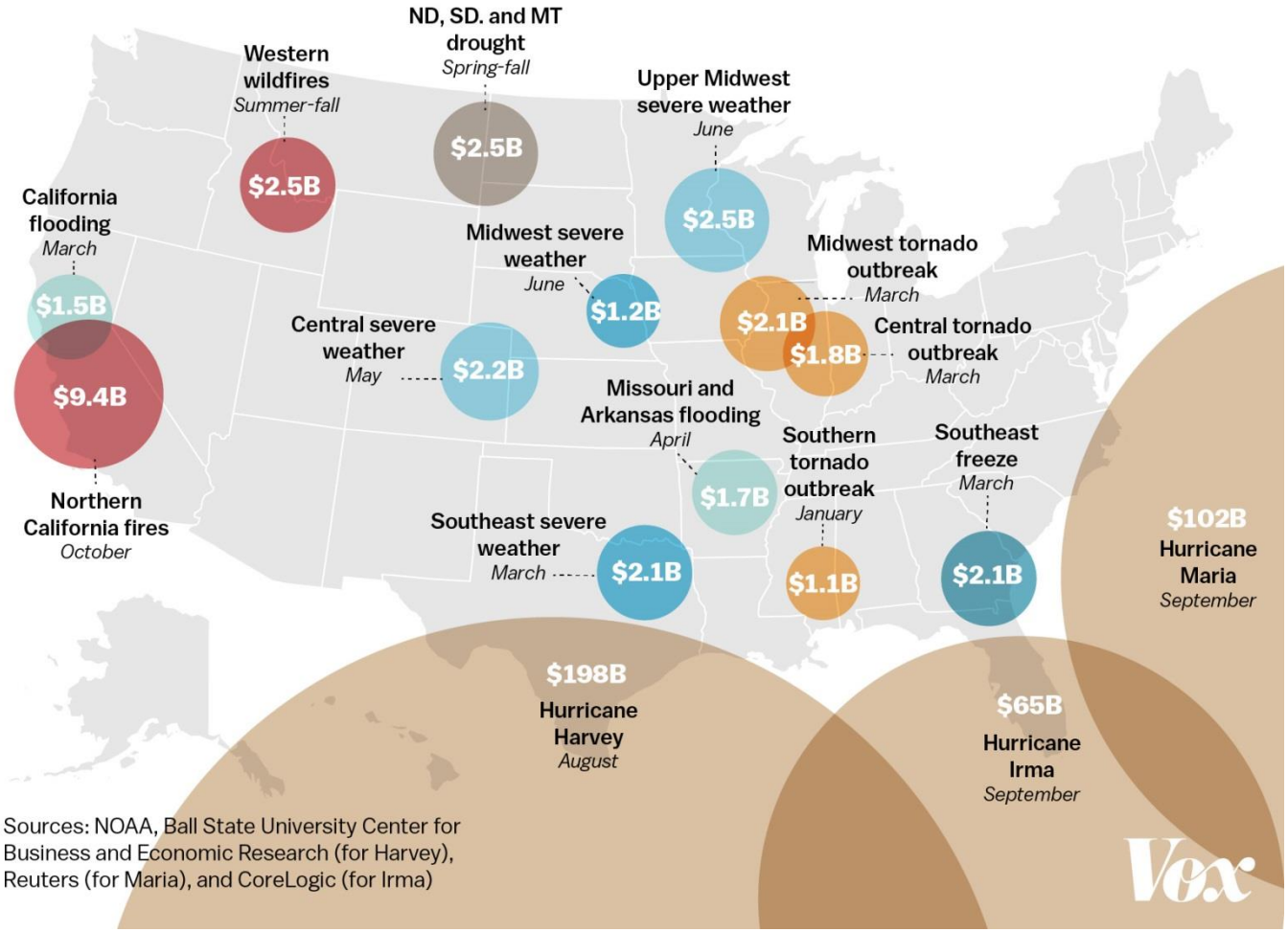
Impacts of Wildfire to the Grid

- Recent wildfires in California raised concerns regarding the proximity of electric equipment to highly populated areas

- Electric equipment can cause wildfires, and is also damaged by wildfires from power lines to in-home smart meters

- Different conditions cause different fire types and profiles.
  - Santa Ana wind fires have been responsible for half of all acres burned, but 80% of the economic losses
  - Non-Santa Ana fires were responsible for 70% of suppression costs

Events in 2017 Cost the U.S. Billions in Weather-Related Damage



Current Decisions Affect Future Electric Sector

- California and its electric grid are already experiencing the impacts of climate change.

- Knowing what the research foresees for the future helps align current decisions with future reality because the past is no longer the predictor of the future.

- Investments in climate mitigation to reduce emissions will pay dividends, as will investments in climate adaptation because the research demonstrates that the changes are happening and will continue to happen.

Presentation Summary

- There is significant evidence of climate changes already taking place in California and around the globe including increased temperatures, drought, wildfire, and sea levels.

- The sooner that mitigation strategies are implemented the lesser the impacts

- Most changes will happen with increased volatility, not with a smooth transition to a new normal

- Even with aggressive mitigation strategies, adaptation measures must be implemented due to projected impacts

Links to Reports

- US Global Research: https://www.globalchange.gov/
- Cal-Adapt.org: http://cal-adapt.org/
- Wind Power Decreasing: https://www.nature.com/articles/s41561-017-0029-9
- Rising Seas in California: http://www.opc.ca.gov/webmaster/ftp/pdf/docs/rising-seas-in-california-an-update-on-sea-level-rise-science.pdf
- Our Coast, Our Future: http://data.pointblue.org/apps/ocof/cms/
- Lawrence Berkeley National Labs study on Artic Ice Loss: https://www.nature.com/articles/s41467-017-01907-4
- NASA study on Mega Droughts: https://www.nasa.gov/press/2015/february/nasa-study-finds-carbon-emissions-could-dramatically-increase-risk-of-us

Links to Reports (con't)

- Water usage for power sector: https://www.ucsusa.org/clean-energy/energy-water-use/water-energy-electricity-overview#.WjlmHHa1t7c
- Atmospheric River research: https://www.esrl.noaa.gov/psd/arportal/

  http://journals.ametsoc.org/doi/10.1175/JCLI-D-16-0544.1
- UCLA Wildfire Study: http://iopscience.iop.org/article/10.1088/1748-9326/10/9/094005/meta